

Charles River Analytics

Annual Progress Report No. R1219811

Reporting Period: Aug 28, 2014 – Aug 28, 2015

Government Contract No. N00014-13-C-0359

Total Award Value: \$767,388

Charles River Analytics Contract No. C12198

Mobile, Virtual Enhancements for Rehabilitation (MOVER)

Annual Progress Report

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Aug 28, 2015

Topic Number: ONR-BAA12-013

Award No.: N00014-13-C-0359

Contractor Name: Charles River Analytics Inc.

Contractor Address: 625 Mount Auburn Street,
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Report Documentation Page			Form Approved OMB No. 0704-0188	
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1. REPORT DATE 28 AUG 2015	2. REPORT TYPE	3. DATES COVERED 28-08-2014 to 28-08-2015		
4. TITLE AND SUBTITLE Mobile, Virtual Enhancements for Rehabilitation (MOVER)			5a. CONTRACT NUMBER	
			5b. GRANT NUMBER	
			5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)			5d. PROJECT NUMBER	
			5e. TASK NUMBER	
			5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Charles River Analytics,,625 Mount Auburn Street,,Cambridge,,MA,02138			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)	
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited				
13. SUPPLEMENTARY NOTES				
14. ABSTRACT Injured Warfighters return home to face long-term care and recovery in addition to life adjustments. Rehabilitation services???such as interventions for traumatic brain injury (TBI)- induced motor limitations, broken bones, spinal cord injuries, chronic pain, and amputation enable these Warfighters to adjust to new living constraints and conditions and, in many cases return to full health. While these services are readily available in military treatment facilities (MTFs) and veterans affairs medical centers (VAMCs), not all patients have the time or ability to receive prolonged inpatient rehabilitation interventions. Furthermore, lengthy inpatient treatments are costly to MTFs and VAMCs, reducing the overall number and types of services that these facilities can provide. For these reasons, home-based and				
15. SUBJECT TERMS				
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 29
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified	19a. NAME OF RESPONSIBLE PERSON	

INTRODUCTION AND EXECUTIVE SUMMARY

Research Goals

Injured Warfighters return home to face long-term care and recovery in addition to life adjustments. Rehabilitation services—such as interventions for traumatic brain injury (TBI)-induced motor limitations, broken bones, spinal cord injuries, chronic pain, and amputation—enable these Warfighters to adjust to new living constraints and conditions and, in many cases, return to full health. While these services are readily available in military treatment facilities (MTFs) and veterans' affairs medical centers (VAMCs), not all patients have the time or ability to receive prolonged inpatient rehabilitation interventions. Furthermore, lengthy inpatient treatments are costly to MTFs and VAMCs, reducing the overall number and types of services that these facilities can provide.

For these reasons, home-based and outpatient rehabilitation interventions hold great potential to improve the rehabilitation of our Warfighters. These rehabilitation interventions enable patients to continue with their daily lives during rehabilitation. Patients can perform professional duties; be with family; and be social with friends around the schedule of their rehabilitation practice, and all of these functions enable patients to better adjust to life changes that follow injury. Home-based and outpatient rehabilitation interventions are accessible to a wide range of patients because they lower the time and travel requirements of rehabilitation. Finally, home-based and outpatient rehabilitation interventions are less costly to MTF and VAMC service providers, enabling these facilities to provide a wider range of services to more patients.

The patient must practice therapeutic exercises regularly. The unfortunate reality of many home-based and outpatient therapies is that the patient does not regularly practice therapeutic exercises beyond visits with the therapist and, therefore, does not see significant improvement. Studies of home-based and outpatient rehabilitation interventions have identified a number of key correlates to lack of adherence: confusion about exercises; perceptions of lack of time to exercise; forgetting to exercise; perceptions of helplessness; and overall lack of motivation to exercise (Jette et al., 1998; Sluijs, Kok, & van der Zee, 1993). Conversely, patients who have less confusion, make time to exercise, remember to exercise, perceive higher self-efficacy, and report motivation to exercise adhere more regularly to rehabilitation protocols. In addition to these areas of needed patient assistance, outpatient therapists must be enabled to perform their job functions of observing the patient and directing exercises.

For these reasons, remote assistance to home-based and outpatient rehabilitation is needed to enhance the recovery of our injured Warfighters.

Description of the Technical Approach

To address these issues, we are developing mobile, virtual enhancements for rehabilitation (MOVER), a mobile, technology-enabled home-based rehabilitation intervention delivery system. MOVER features (1) a mobile application to provide education, information, and scheduling of therapeutic exercises; (2) virtual coaches to guide, mentor, and motivate patients; (3) COTS input devices and video games to increase patient motivation; and (4) a web-based therapist interface to accurately assess patient adherence and progress.

Figure 1 shows the MOVER Architecture. At the top left of the figure, the **Patient** interacts with the **MOVER Mobile Application** to perform **Exercise Scheduling** and obtain **Information and Education** about therapeutic exercises. The **Virtual Coaches** exist on the mobile application and provide interactive guidance and mentoring about the rehabilitation process and therapeutic exercises. When the scheduled time for the exercises arrives, the mobile application reminds the patient, and the patient begins an exercise session with the **MOVER Game Integration**, as shown at the bottom of the figure. The patient uses **COTS input devices**, such as the Microsoft Kinect and the Wii Balance Board, to perform therapeutic exercises that are mapped to controls of the **Video Game Console** through the **Control Mapping on Laptop**, software running on an inexpensive PC or laptop.

During interaction with the mobile application and game integration, patient **Performance** is recorded and sent securely to the **Remote Server** and **Secure Database**, at the center of the figure. The **Therapist** reviews this performance through summarized **Progress Reports** in the web-based **Therapist Interface**, as shown at the top right of the figure. The therapist then creates **Therapeutic Exercise Assignments** to describe the patient's therapeutic exercises for the next week, and these assignments are passed to the game integration for implementation the next time the patient begins exercise.

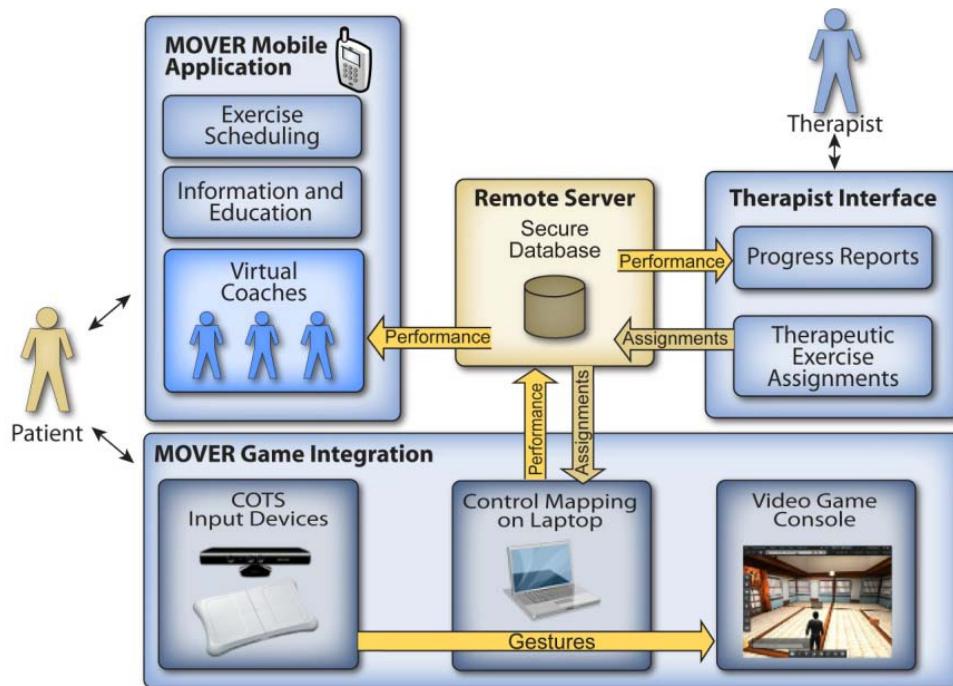


Figure 1: MOVER architecture

A typical use of MOVER in home-based rehabilitation is as follows. The patient meets with the therapist at the beginning of the week to participate in a short, one-on-one rehabilitation session. The therapist assesses the patient, prescribes a set of therapeutic exercises for the week, and works with the patient to determine a feasible exercise schedule. At the end of the session, the patient and therapist enter an exercise schedule for the week, and the therapist enters the therapeutic exercises into the therapist interface. During the week, the patient is

reminded of scheduled exercises by the mobile application and motivated by the virtual coaches. The patient uses the COTS input devices to play the video games with the therapeutic movements specified by the therapist. During exercise, the virtual coaches give feedback on patient movements and form, and afterwards the virtual coaches review the patient performance. Performance information is collected and sent to the remote server. At the next session, the therapist reviews the progress reports with the patient to determine next steps for treatment.

Deliverables/Milestones Schedule

Tasks	Months:	2	4	6	8	10	12	14	16	18	20	22	24									
Task 1: Requirements Analysis		SME Interviews	User Feedback																			
				Requirements Iterations																		
Task 2: Mobile Application Development		Initial Dev.	Evaluation Prototype Dev.										Docs									
			Initial Prototype				Evaluation Prototype					Final Prototype	Docs									
Task 3: Virtual Coaches Development		Initial Dev.	Evaluation Prototype Dev.										Docs									
			Initial Prototype				Evaluation Prototype					Final Prototype	Docs									
Task 4: Input Device and Game Integration		Initial Dev.	Evaluation Prototype Dev.										Docs									
			Initial Prototype				Evaluation Prototype					Final Prototype	Docs									
Task 5: Remote Server and Therapist Interface Development		Initial Dev.	Evaluation Prototype Dev.										Docs									
			Initial Prototype				Evaluation Prototype					Final Prototype	Docs									
Task 6: Evaluation		Experiment Preparation and Recruitment			Experimentation			Data Collected			Analysis											
		Experiment Materials, Staff, and Subjects Ready						Data Analyzed														
Task 7: Program Management		Program Management																				
Task 8: Final Report																						
Deliverables	Presentations	Kickoff Briefing											Report									
	Technical and Financial Reports	Status	Status	Status	Status	Interim							Final Report									
	Software and Documentation				Evaluation Prototype	Status	Status	Status	Status	Status			Final Briefing									
						Status	Status	Status	Status	Status			Final Prototype									

TECHNICAL PROGRESS

Progress against Planned Objectives

During this reporting period, we focused on Task 2 (Mobile Application Development), Task 3 (Virtual Coaches Development), Task 4 (Input Device and Game Integration), Task 6 (Evaluation), Task 7 (Program Management), and Task 8 (Final Report) as presented in the Statement of Work for this effort.

We attended the Military Health System Research Symposium (MHSRS) and met many members of the operational military health community, including program officers from

relevant military labs such as the Congressionally Directed Medical Research Program (CDMRP).

Technical Accomplishments This Period

Task 2: Mobile Application Development

Our goal for Task 2 is to develop a mobile application to accompany home-based TBI motor impairment rehabilitation therapy. Given our design for a reminder-based system, which is already available on most smartphones and tablets, we have chosen to focus the majority of our development and prototyping efforts on the unique aspects of MOVER that will be tested in early pilots. These are the virtual coach, the Kinect hardware integration, and the integrated games. Should the need arise for a mobile application to support at-home trials, we will make use of these available technologies and integrate them as necessary to support patient needs.

Task 3: Virtual Coaches Development

Our goal for Task 3 is to develop virtual coaches to assist home-based TBI motor impairment rehabilitation therapy through mentoring and guidance. During the current reporting period, we designed a therapist interface to create and edit exercises and schedules for individual patients. Figure 2 shows a mockup of the exercise routine editor. On the left, the therapist can assign new exercises to the patient by creating them or selecting exercises from a library. In the middle, exercise information is editable, including the name, purpose, notes, goal, number of sets, number of repetitions, and introduction text.

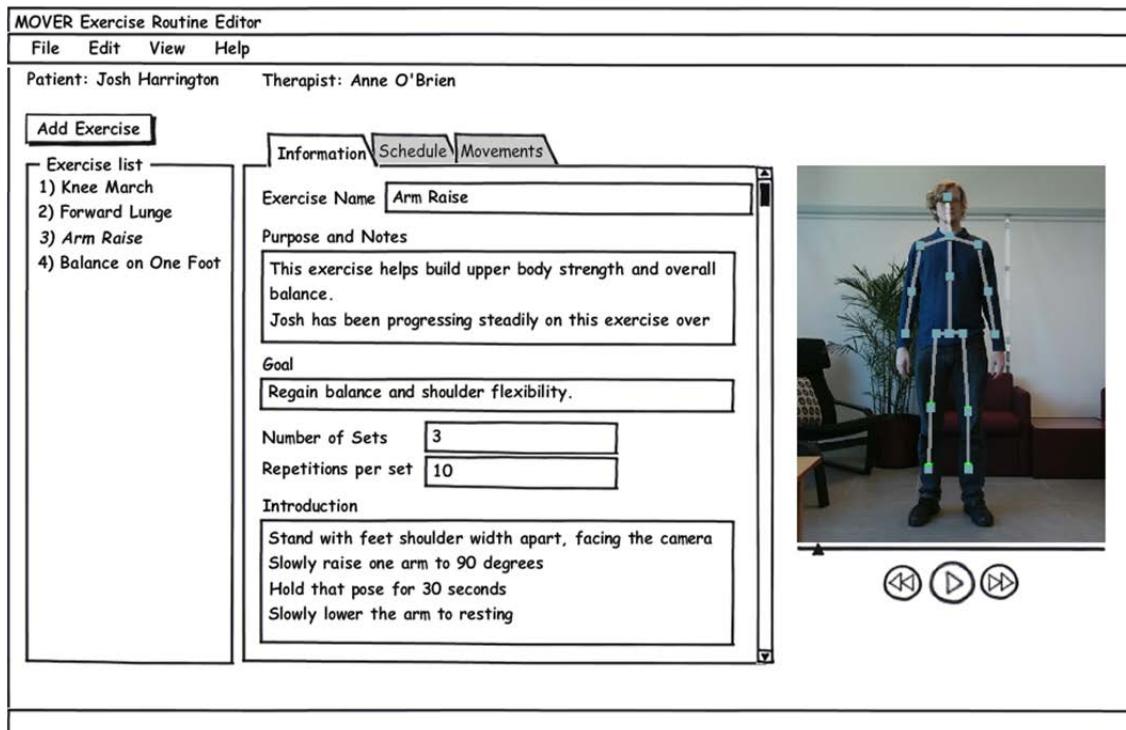


Figure 2: MOVER exercise routine editor mockup, exercise information

Figure 3 shows the prototype exercise editor created from this early mockup. The editor allows the capture of recorded pose data from the Kinect and the mark-up of that data to specific distance and angle constraints on exercises within time segments. For example, a therapist may record a patient performing leg lift exercises, and specify that the knee reach a 90 degree angle during the middle of a repetition. Upon showing this interface to the therapist SMEs at Spaulding, we determined that the specification of time segments and constraints was overly complex for the end user, and we have elected to reserve this tool for developers to create new exercises for the MOVER system.

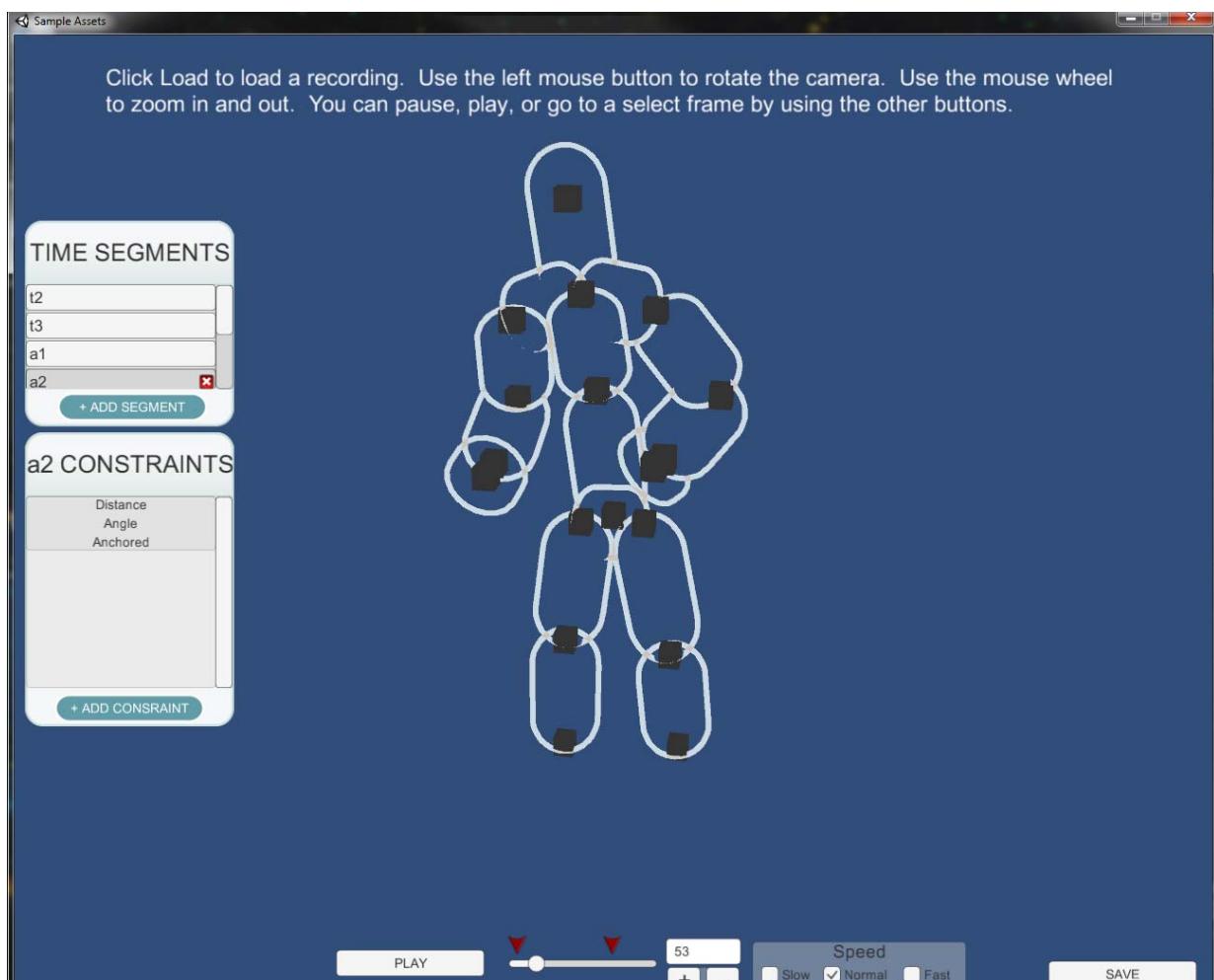


Figure 3: Prototype exercise editor

In place of having an exercise creation tool for the therapists, we have simplified the process by hardcoding specific, commonly used balance exercises into the system and enabling the therapists to select and customize pre-identified parameters for these exercises. Figure 4 shows the exercise routine selection screen. Each exercise has a custom set of parameters. For example, Figure 5 shows the height setting for the knee lift exercise. The therapist selects the height that the patient attempts to achieve during each knee lift, and the height is visualized as a vertical percentage slider and red bar over the patient as a point of reference.

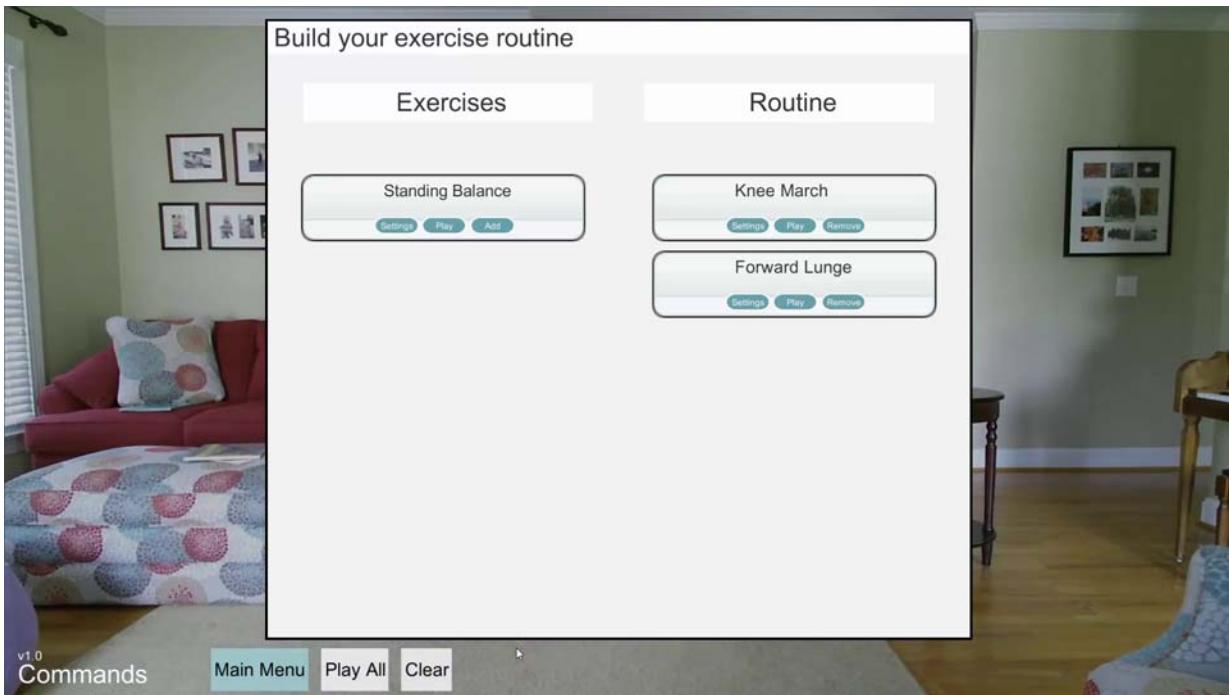


Figure 4: Exercise routine selection

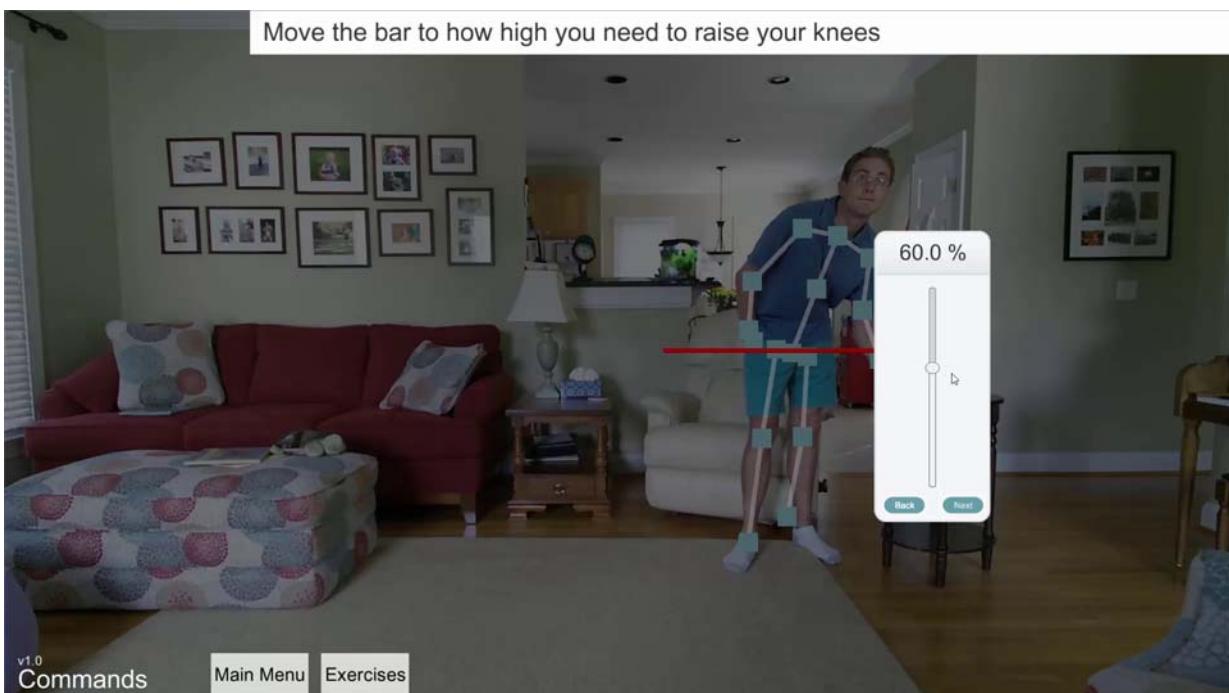


Figure 5: Knee lift knee height setting

Once the exercises have been selected and configured, the patient may run their personal exercise routine through the system. Figure 6 shows the knee lift exercise, with target bar and

active leg highlighted. Figure 7 shows the virtual coach feedback during this exercise if the patient begins leaning too much in one direction. We have minimized the on screen interruption of the virtual coach by providing a vertical guide bar, highlighting the torso points of reference, and displaying the corrective message at the top of the screen. The virtual coach counts the repetitions of the exercise up to the pre-configured amount, and then a summary screen recaps the accomplishment, as shown in Figure 8. The exercises may also be completed without the “skeleton” overlay visualization (i.e., the blue boxes and lines between them), as shown in Figure 9.

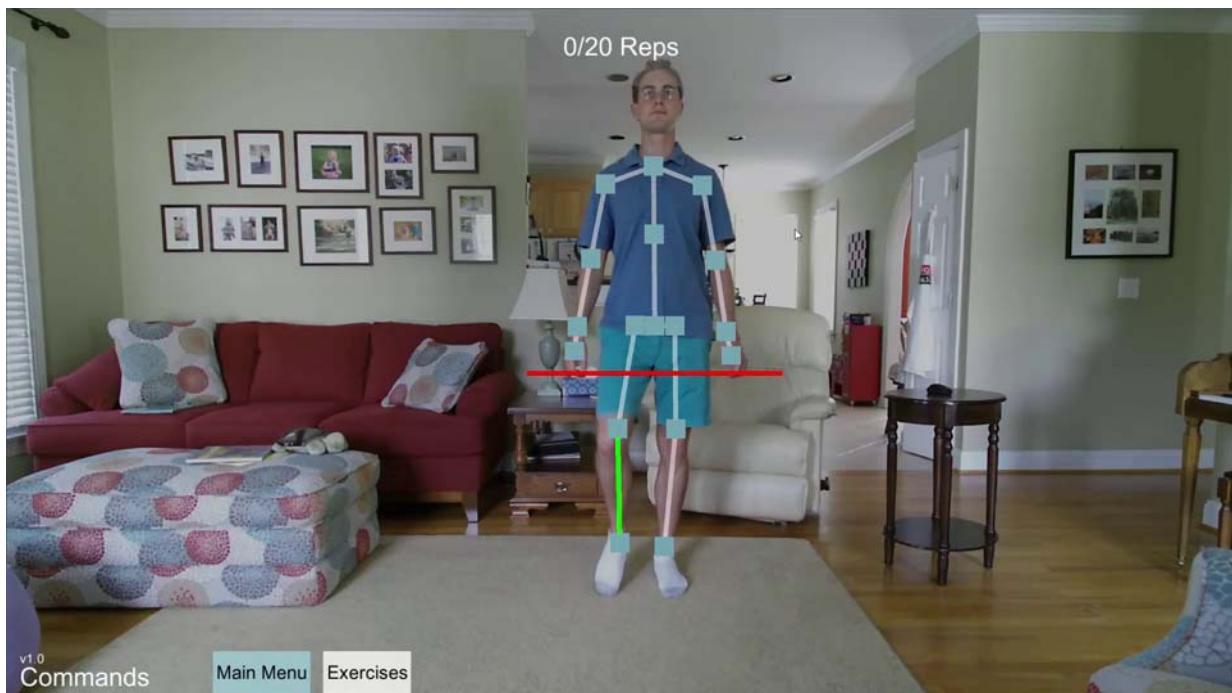


Figure 6: Knee lift exercise

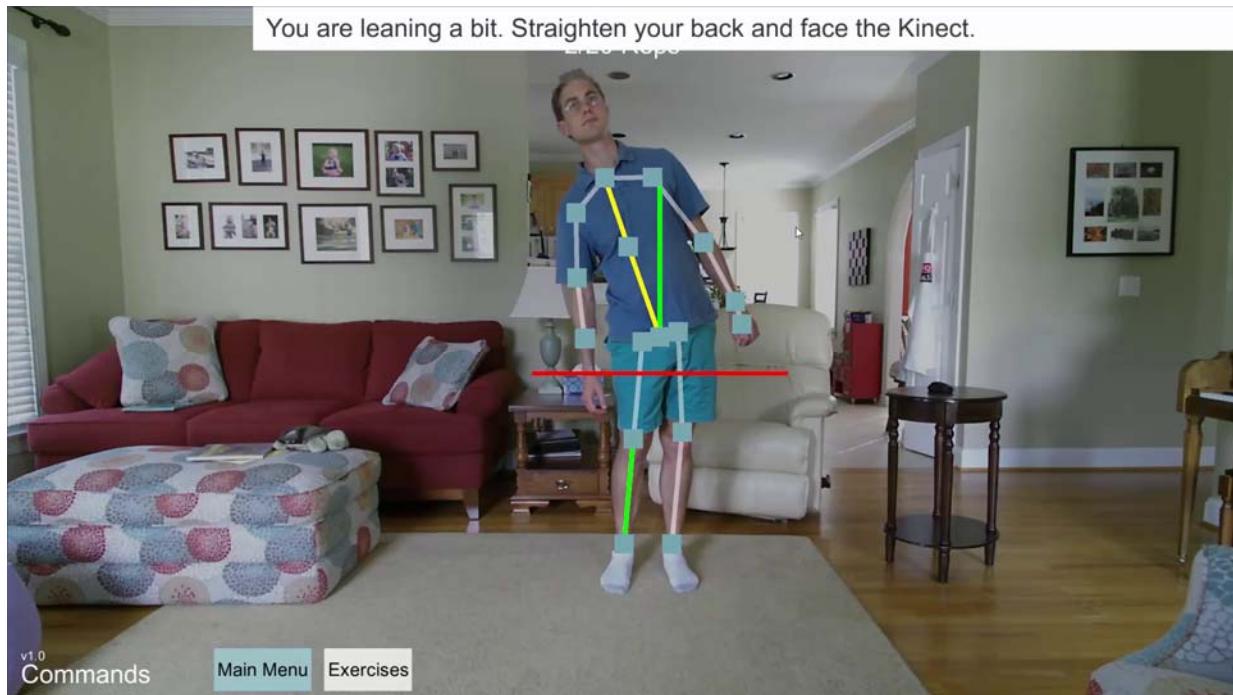


Figure 7: Virtual coach feedback during knee lift exercise

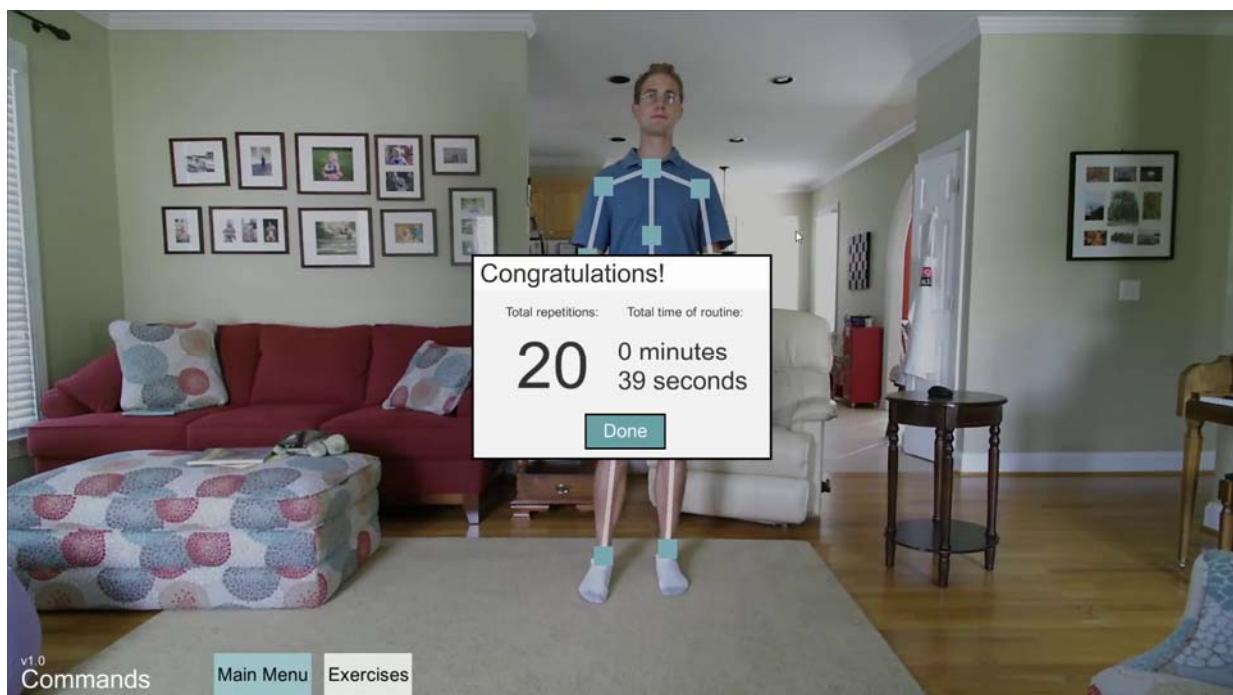


Figure 8: Post-exercise feedback

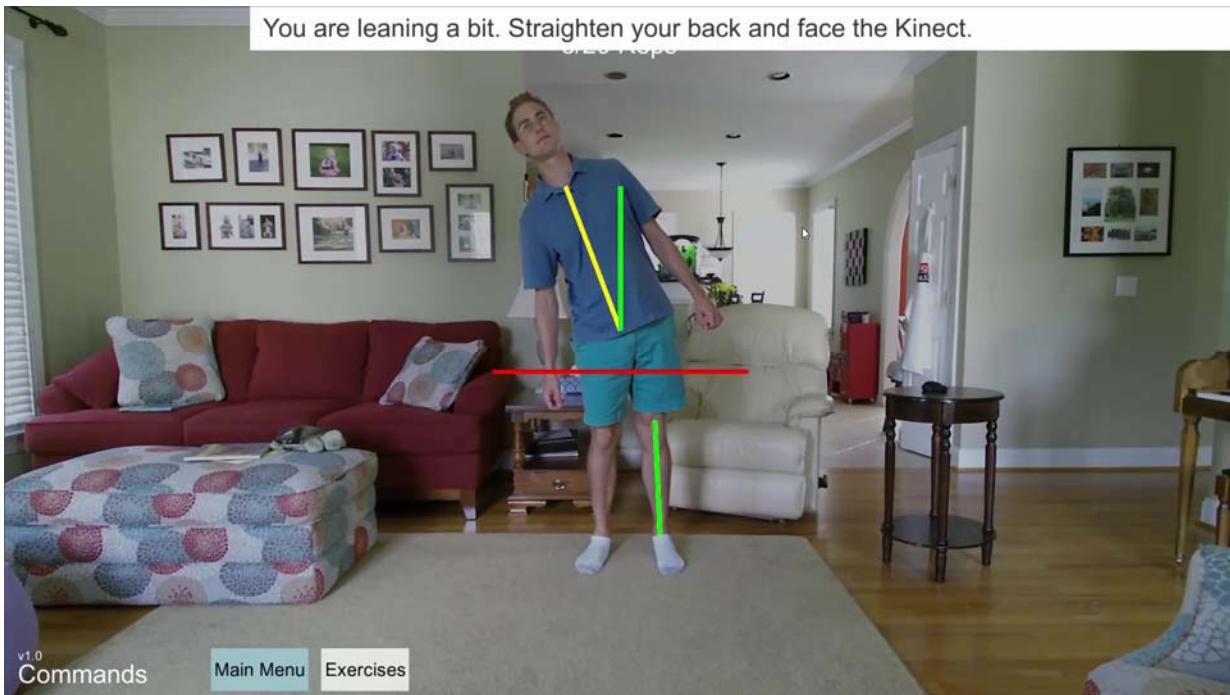


Figure 9: Knee lift exercise and feedback without drawn skeleton

Figure 10 shows the forward lunge exercise, in which the patient must step forward and dip their hips below the red bar. Figure 11 shows virtual coach feedback if the patient leans too far forward and pushes their knee beyond their toes.

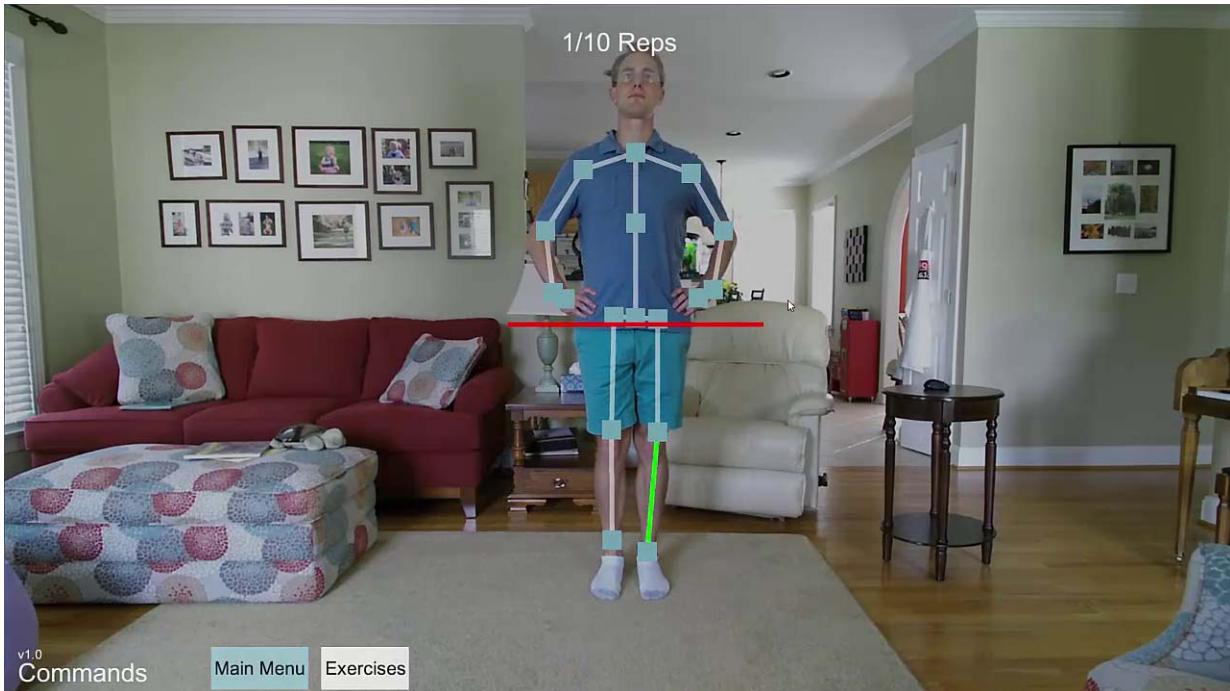


Figure 10: Forward lunge exercise



Figure 11: Virtual coach feedback during forward lunge

In addition to the pre-defined exercises, the therapist can walk the patient through a custom recorded exercise. Figure 12 illustrates this feature. This movement is recorded through the Kinect camera and then played back for each repetition for the patient to follow. The white outlines show the patient where to move, and the skeleton is color-coded with green limbs in the correct position and red limbs out of position.

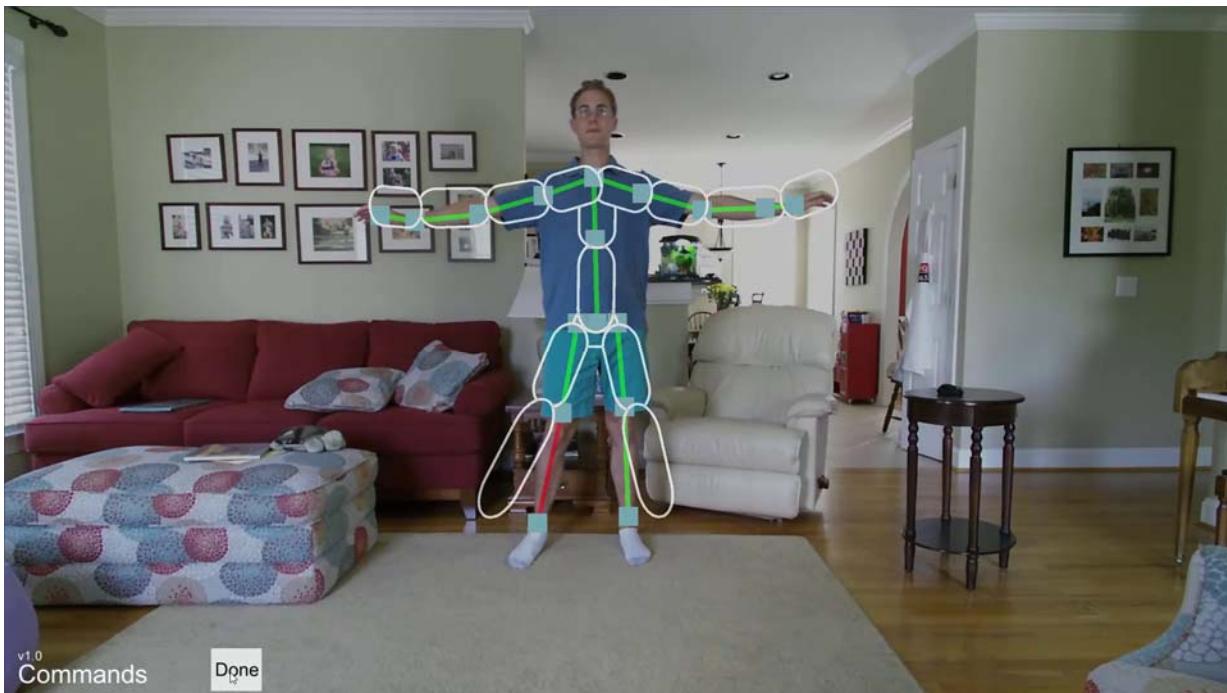


Figure 12: Custom recorded exercise with skeleton coloring feedback

Task 4: Input Device and Game Integration

Our goal for Task 4 is to integrate commercial-off-the-shelf (COTS) input devices and COTS video games to engage the patient and estimate body posture during therapeutic exercises.

During the current reporting period, we addressed many of the engineering hurdles to MOVER's implementation. The technical issues we addressed includes the following list:

- Record Mode
 - Create a record “scene” in which the patient or therapist can record a new exercise, with accompanying user interface elements
 - Save and load a Kinect motion captured exercise for later practice
 - Save and load multiple exercises at once
 - Record joint positions as well as rotations
- Wireframe Skeleton
 - Render the wireframe skeleton, scaled to user size
 - Scale and position the wireframe
- Outline
 - Create an outline view of the exercise as it was recorded
 - scale and position the outline to fit over patient
- Voice input and speech generation
 - Integrate Microsoft voice recognition and speech generation with Unity
- Practice Mode
 - Create a practice “scene” in which the patient is walked through the exercise, with accompanying user interface elements
 - Add a correctly sized skeleton overlay onto the color video frame in Unity

- Display the outline of a motion captured exercise as a target for a patient in practice mode
- Color the skeleton red if it strays outside of the outline view
- Virtual Coach
 - Animate the virtual coach according to the recorded exercise
 - Smooth the virtual coach movements to avoid jitter in recorded exercise
- Video Game Integration
 - Create initial list of therapeutic movements for video game control
- Integration
 - Test with flat screen television and wireless headset mics
 - Record an initial demo video

The result of this development is a new MOVER demo, as shown in Figure 13 and Figure 14. In this demonstration, the user can record and practice an exercise with voice input and visual feedback. Figure 13 shows a user (a stand in for a patient) recording a new exercise. The user stands in front of the camera and says “go to recording” into the wireless headset they are wearing. Once in recording, the user says “begin”, performs the movements of this exercise, and says “done”. The exercise movements are saved to disk for later practice. Figure 14 shows the practice of this exercise. The user again uses the voice commands to enter practice mode. The virtual coach appears on the left and a white outline view appears over the user when the exercise begins. The white outline and virtual coach perform the movement as recorded, and the user follows along, tracked by a green skeleton. If the user gets out of position, the out-of-place skeleton bones are colored red.

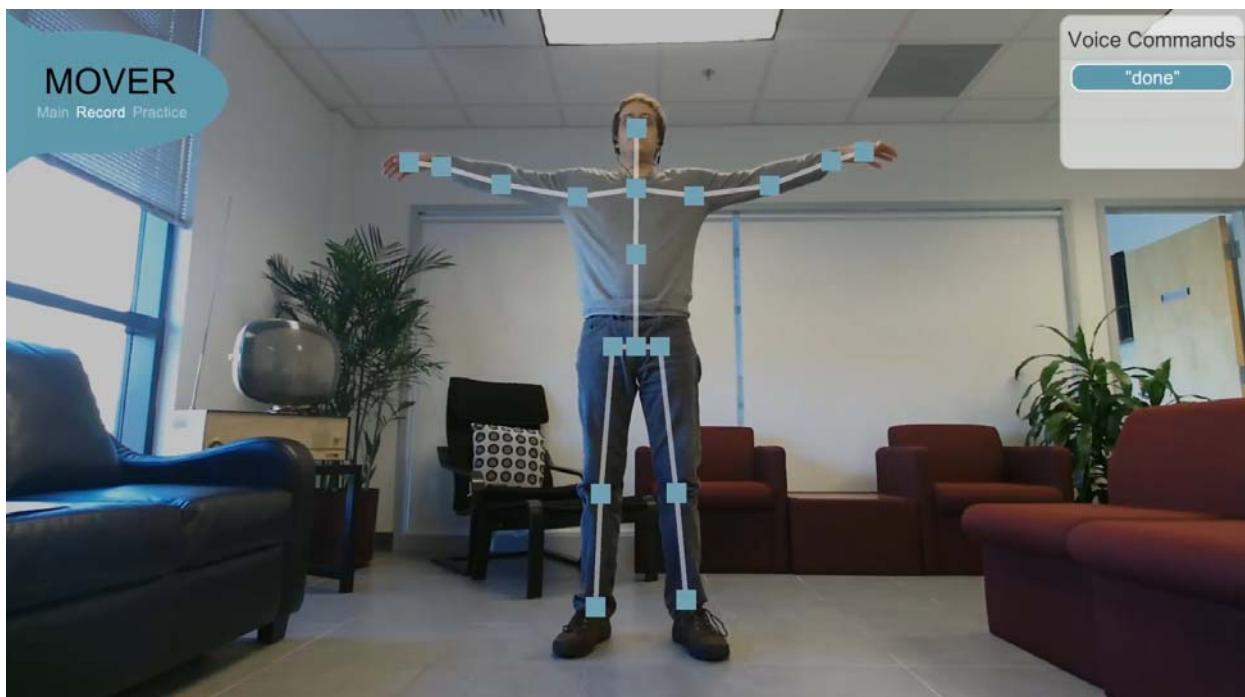


Figure 13: MOVER prototype screenshot, recording

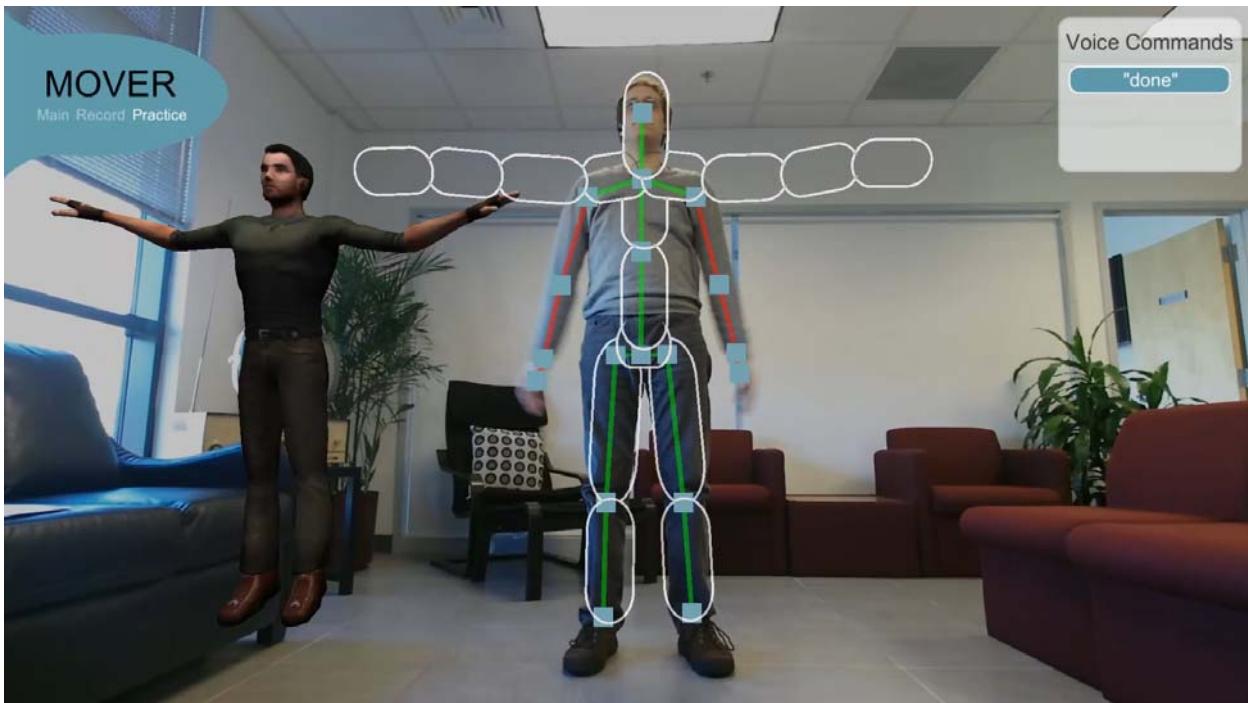


Figure 14: MOVER prototype screenshot, practice

Through providing this early prototype to our therapist SMEs and presenting our plans for commercial game integration, we received several points of feedback, including the following:

1. The voice commands might not work well in our sometimes noisy laboratory test environment. A hand-held mouse or clicker would be easier to use.
2. The exercise screen was too busy with too much going on on the screen. This could negatively affect the ability for TBI patients with visual and cognitive deficits to use the system.
3. Commercial games, while high in entertainment value, are often not well tuned to the needs of TBI patients, especially with the aforementioned visual and cognitive deficits. Instead, the therapists felt the need for simpler games that are highly customizable.

To address these issues, we changed the design of the system in the following ways:

1. We added mouse/clicker support for the menus and removed the voice command requirement.
2. We removed the virtual coach's character from the screen, and removed as much of the overlays as possible while still preserving the core aspects of the exercises.
3. We added a small suite of simple exercise games tuned to motion and balance disorder patients. We made these games highly customizable to enable therapists to tune each game to the capabilities of individual patients.

We implemented these design changes in our current prototype. Figure 15 shows the updated main menu screen, and Figure 16 shows the current selection of games. In Figure 17, upon selecting a game, the user is given an introduction to the objectives of the game and the ability to change the specific game settings. The critter swat game is one in which the user stands in the center of the screen and reaches out to swat targets that appear on the screen around them.

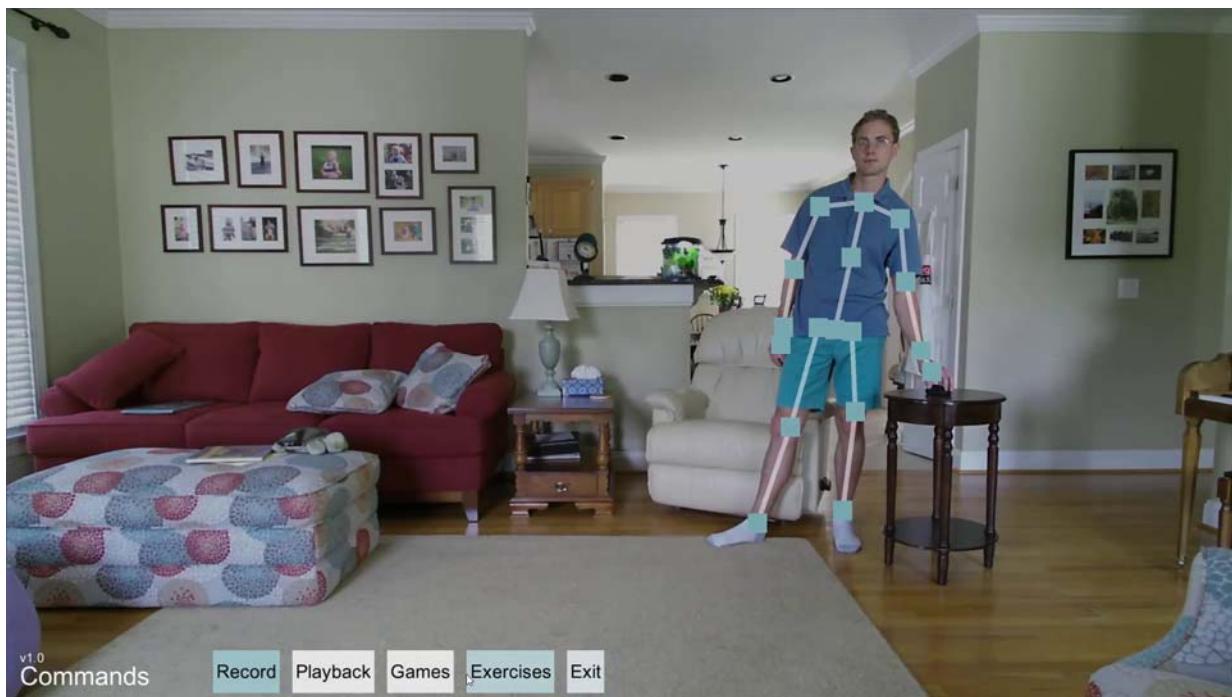


Figure 15: Main Menu Screen

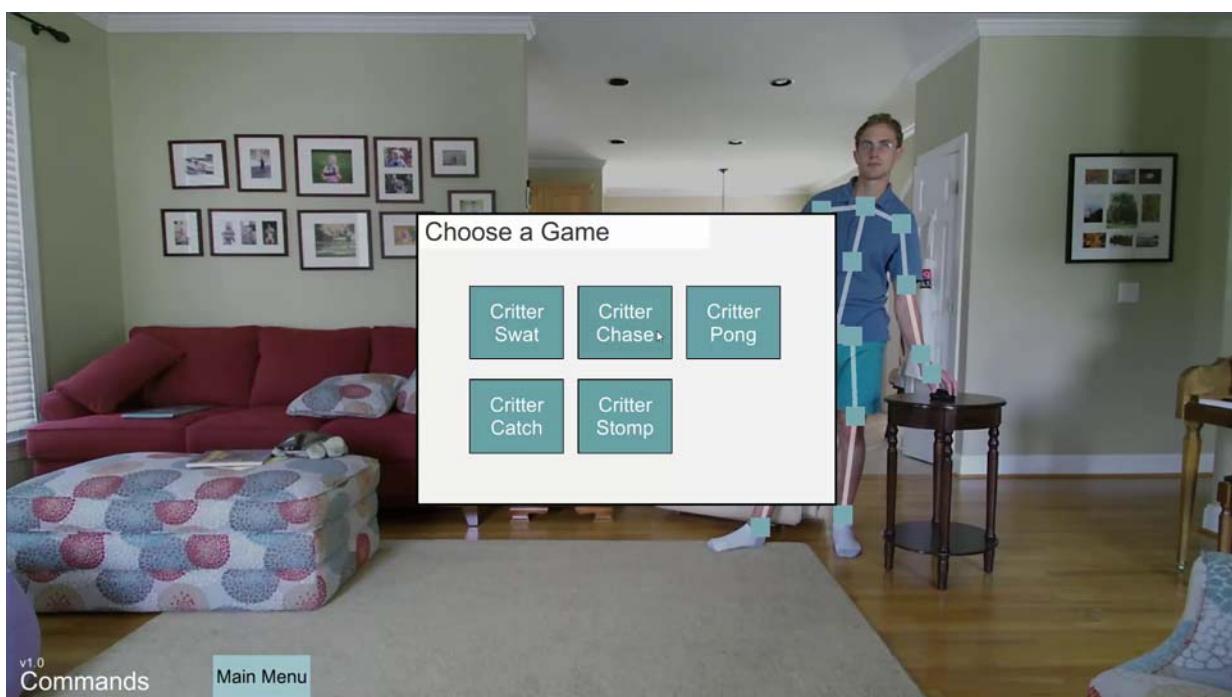


Figure 16: Game Selection

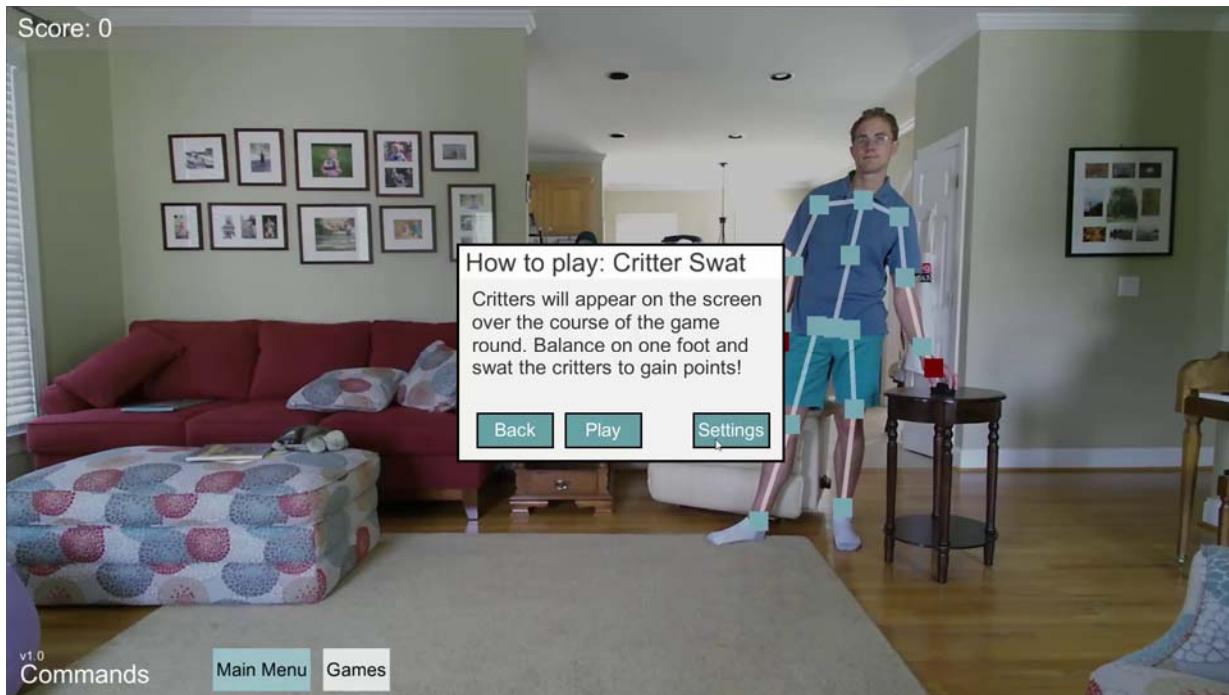


Figure 17: Critter Swat game introduction screen with settings option

Each game includes a host of settings. Figure 18 shows the setting for the target graphic styles. Figure 19 shows the setting for which foot the patient must balance on during the game (left, right, swap halfway through, or both). Figure 20 shows the setting for the length of time the patient must hover over the target before a new target appears. Figure 21 shows the setting for which hand is allowed to reach for which targets. Figure 22 shows the target spawning location selection screen. The therapist can set this location by enabling the motion selection option and allow the patient to move their hands around the screen. This enables the calibration of the exercise to the areas of the screen that the patient can reach without moving. Figure 23 shows the game duration settings.

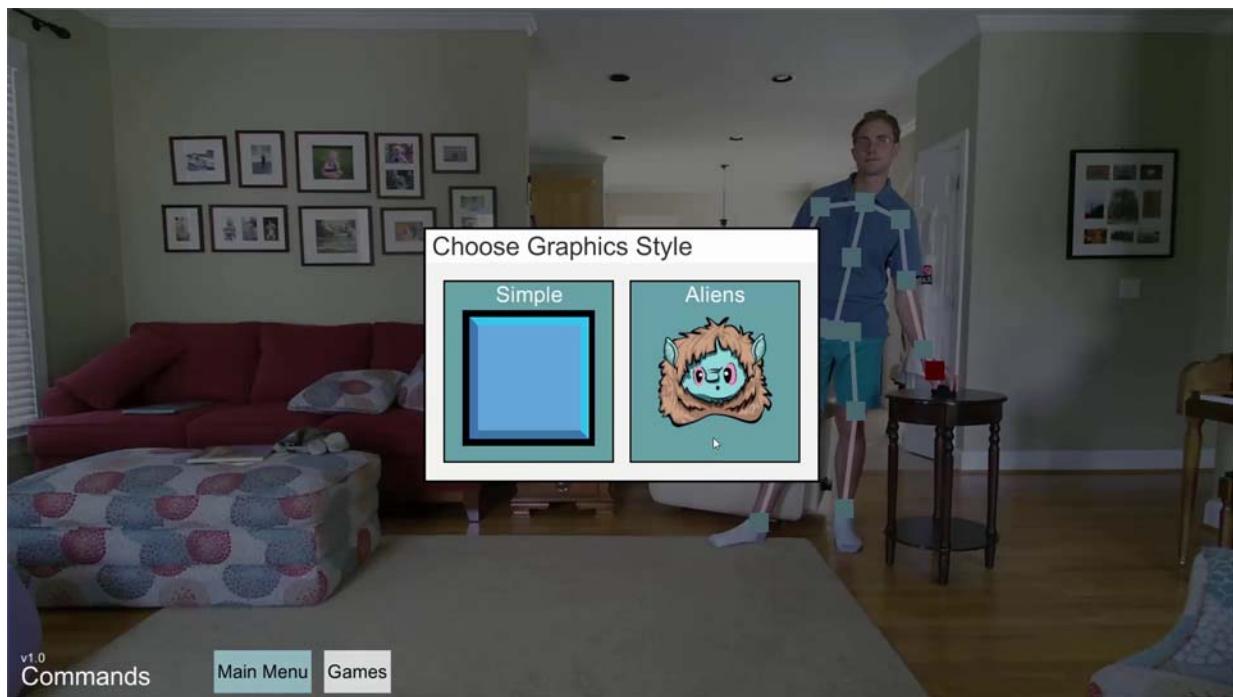


Figure 18: Graphics style settings

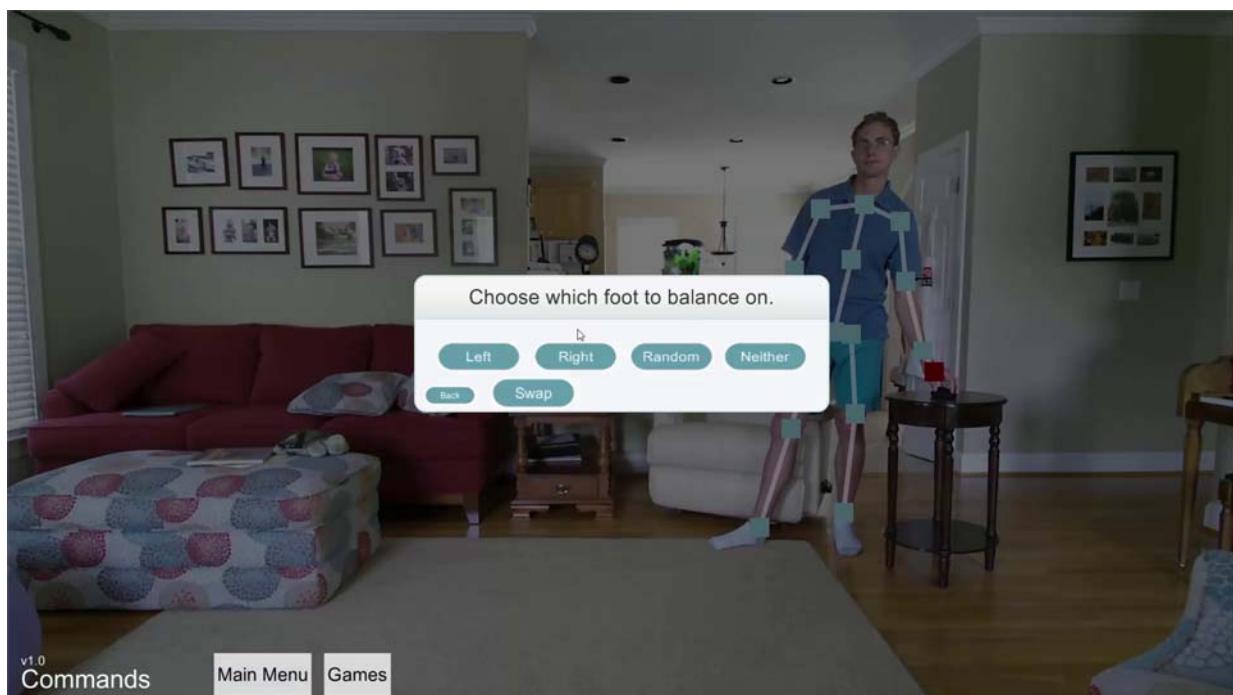


Figure 19: Foot balance settings

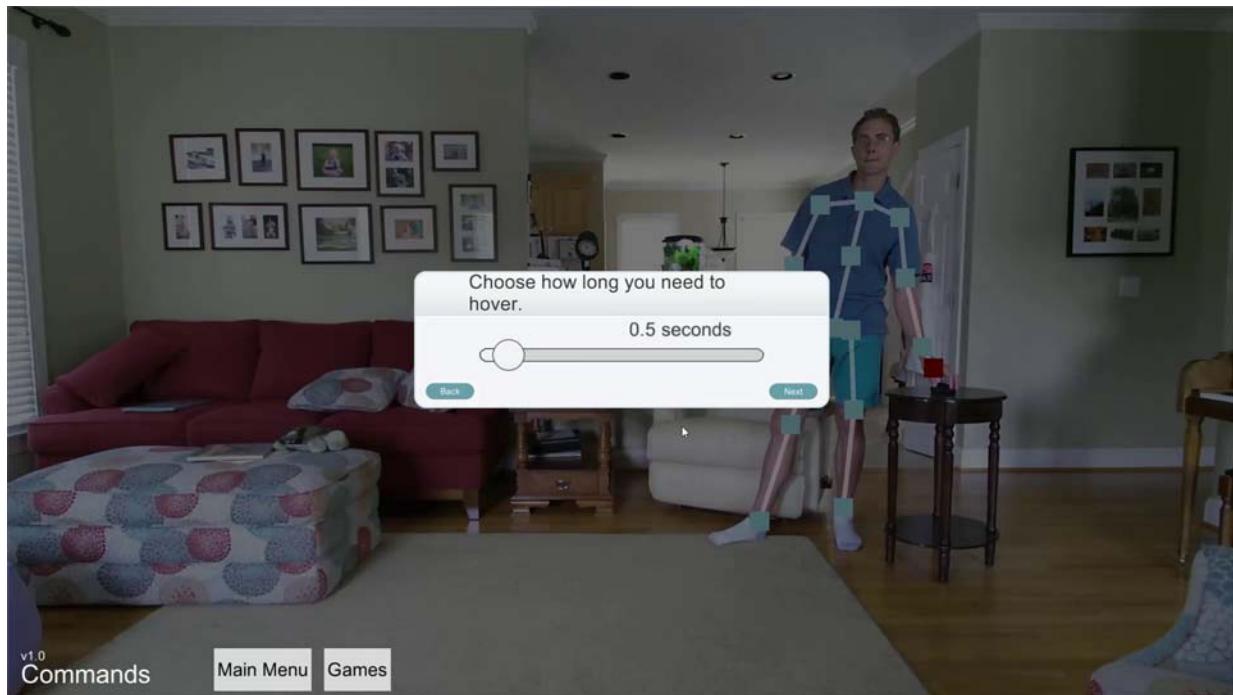


Figure 20: Hover length settings

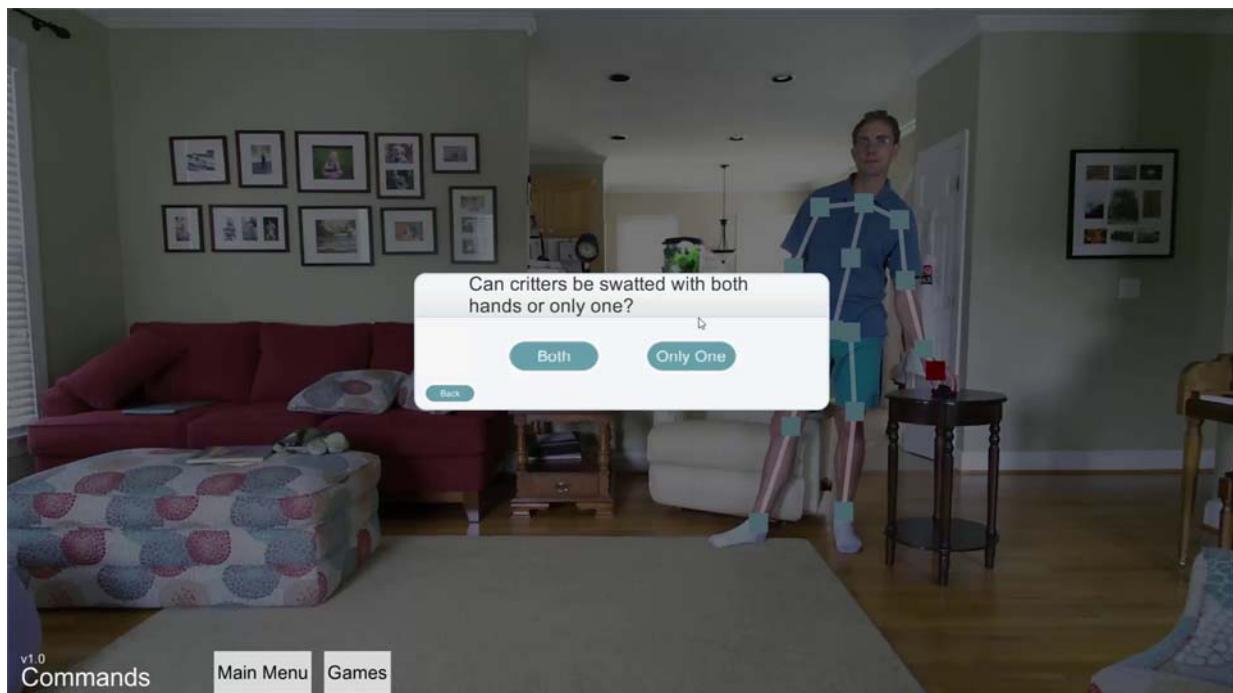


Figure 21: Hand use settings

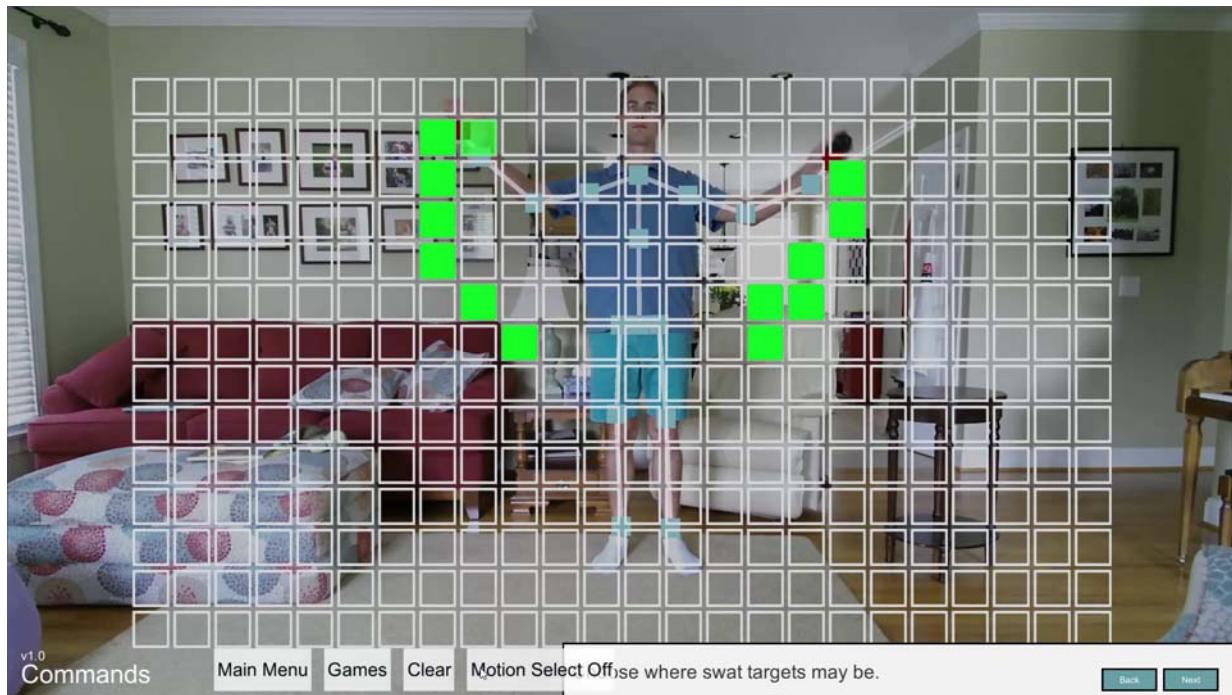


Figure 22: Target location settings

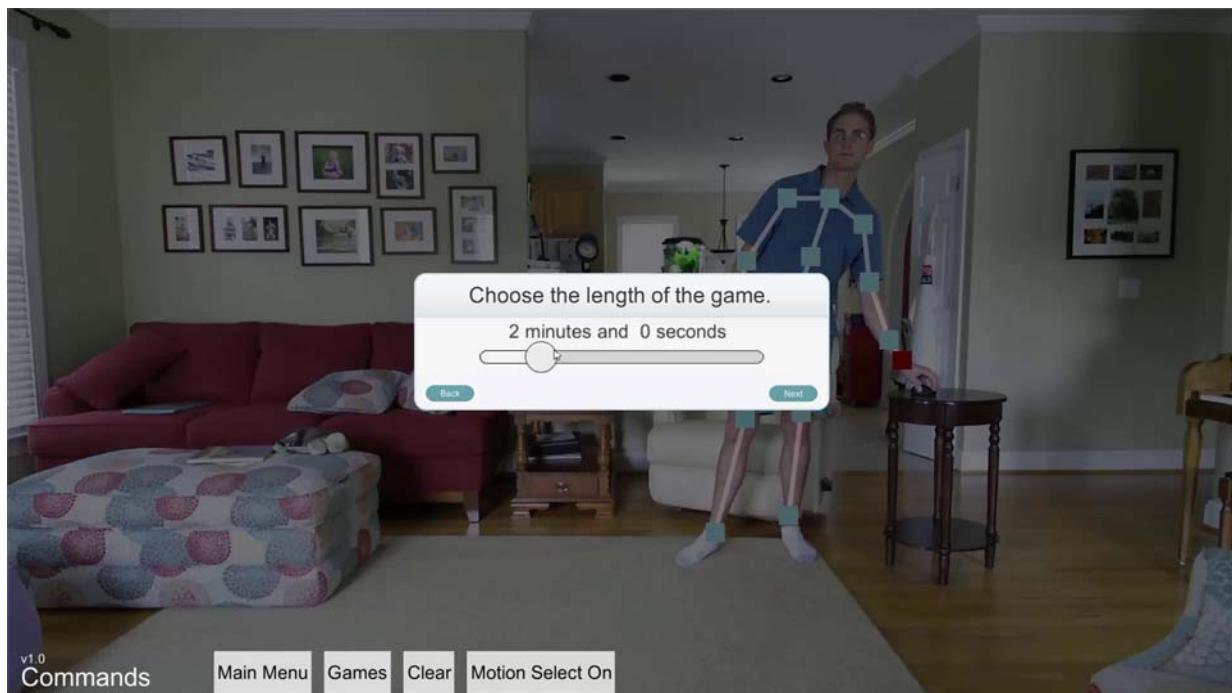


Figure 23: Game duration settings

Playing the games is similar to performing the exercises. In Figure 24 and Figure 25, the patient is instructed to stand in the center of the screen to begin the critter swat game. In Figure 26, the

patient plays the critter swat game by reaching and hovering their hand over targets. In Figure 27, after a set amount of time the game ends and the user is presented with their high score, giving them feedback on their progress.

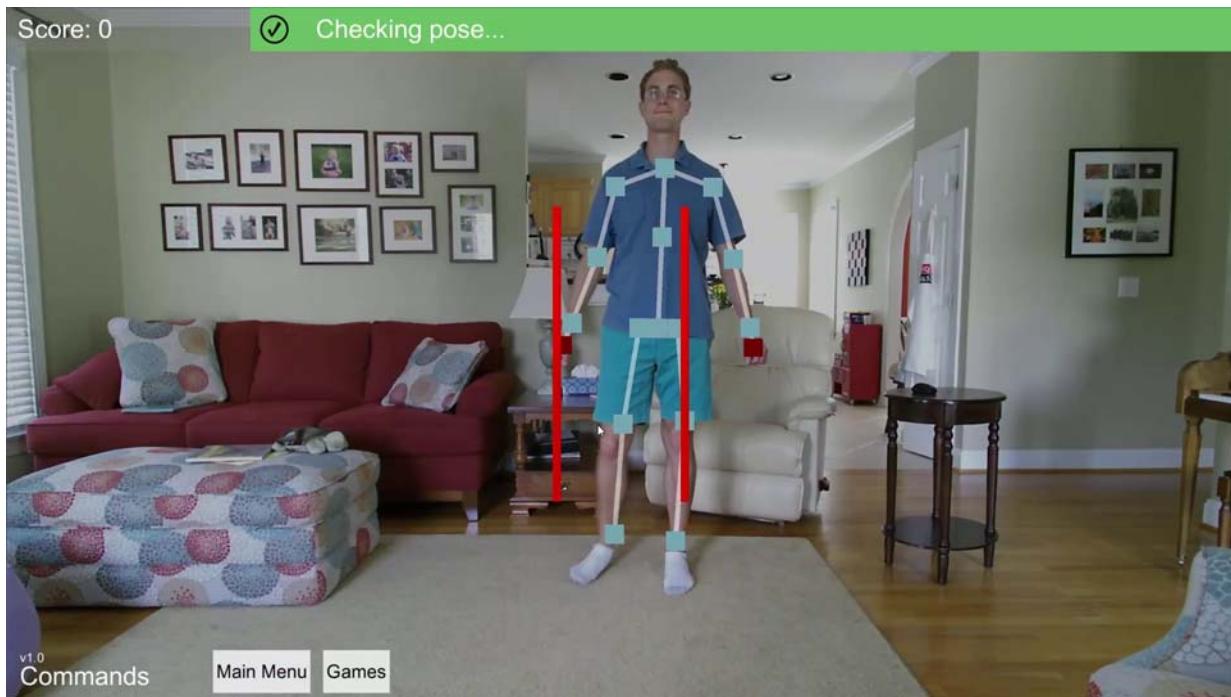


Figure 24: Critter Swat pregame checking location and pose

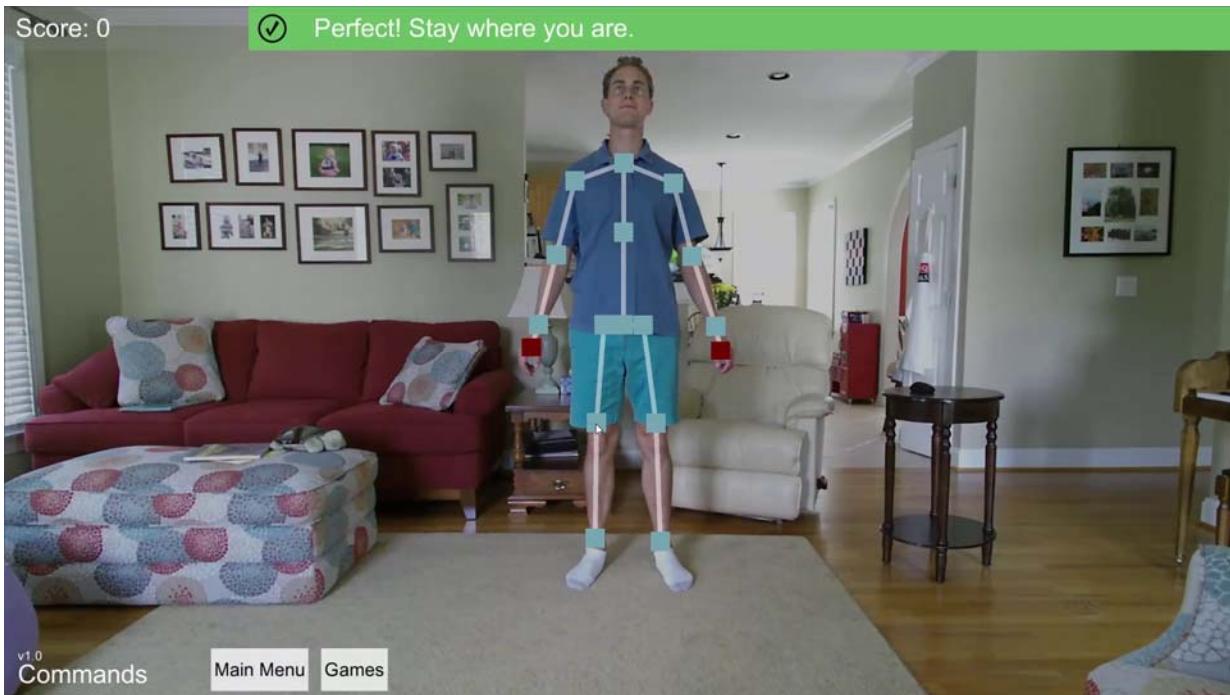


Figure 25: Critter Swat game location and pose achieved

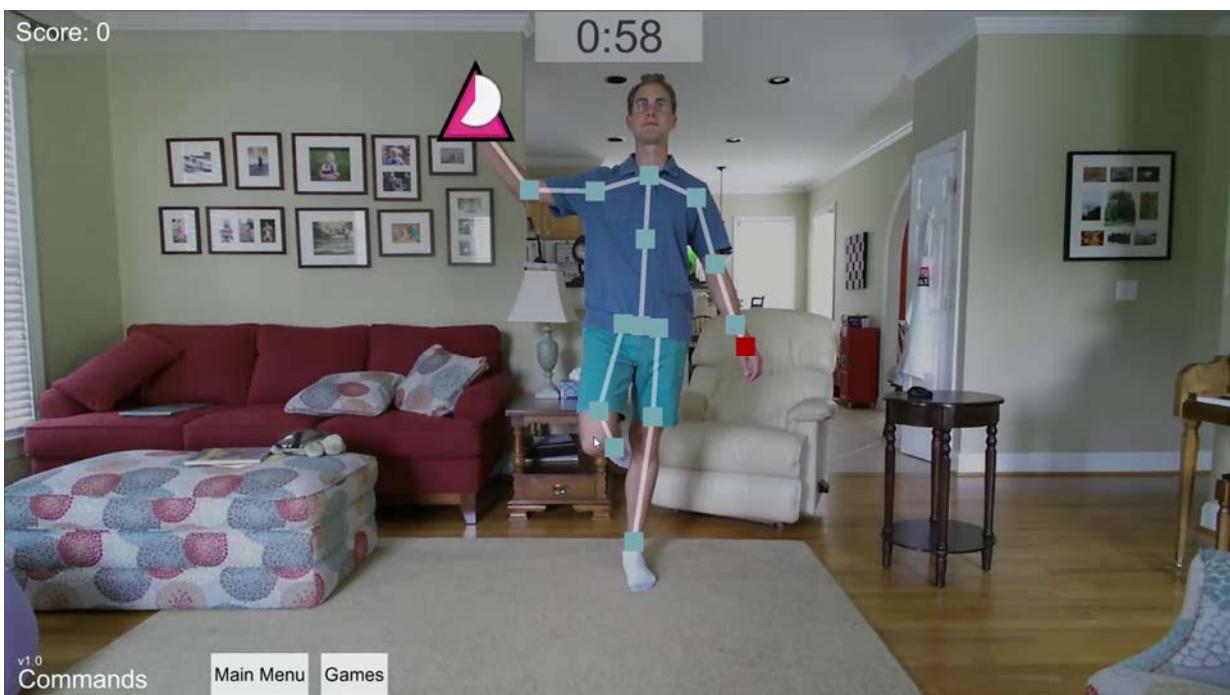


Figure 26: Critter Swat game

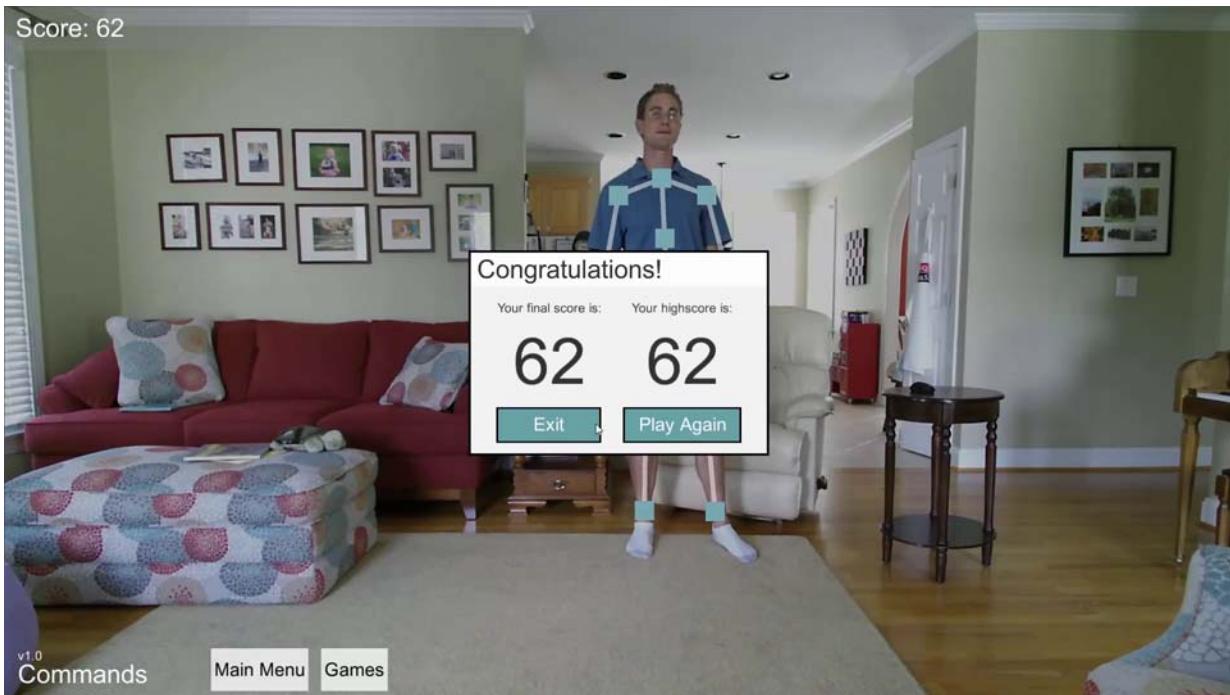


Figure 27: Critter Swat end round and high score screen

We implemented multiple games during the current reporting period. In Figure 28, patients play the critter chase game by roaming around the exercise area and hovering over targets that appear on the screen. In Figure 29 and Figure 30, patients play the critter stomp game by waiting for the targets to enter the screen from the left or right, raising their leg above the configurable red bar, and stomping the target as it comes by. In Figure 31, patients play the critter catch game by shifting left or right underneath the targets falling from the top of the screen to catch them before they fall to the bottom. In Figure 32, each of the games feature feedback if the patient breaks the desired posture. The game pauses to wait for the patient to readjust. In Figure 33, patients play the critter pong game by swatting the targets away as they bounce from the left or the right of the screen.

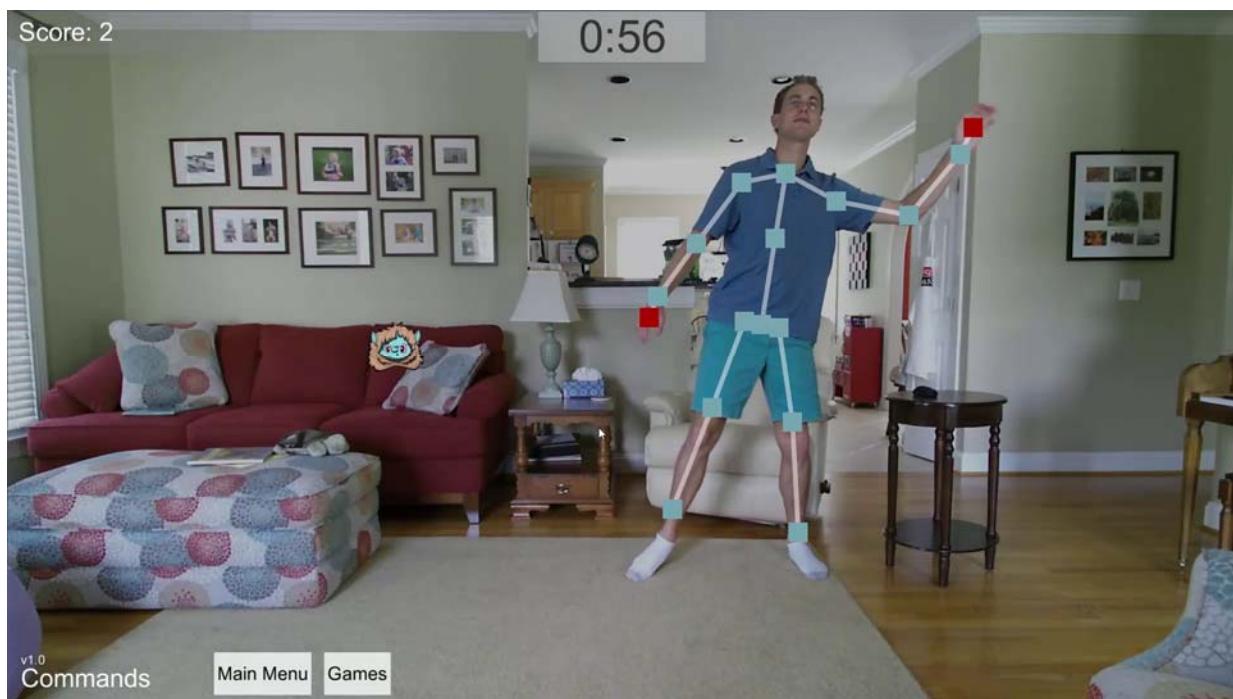


Figure 28: Critter Chase game

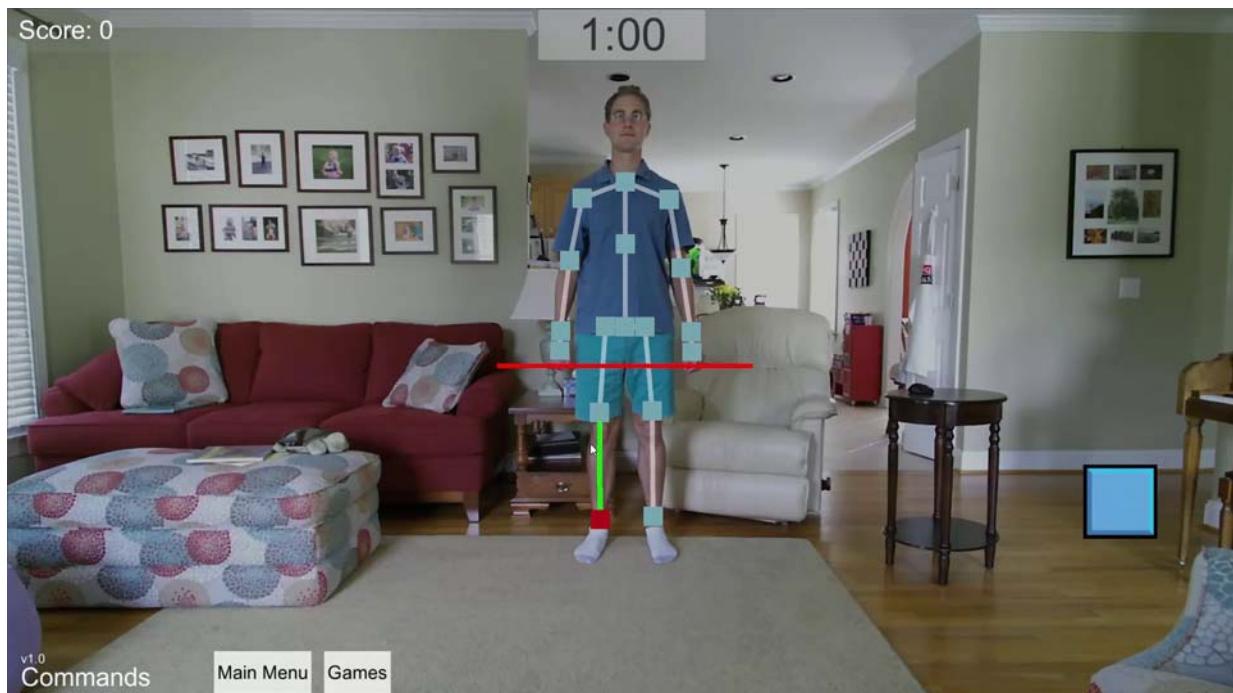


Figure 29: Critter Stomp game, target approaching from right

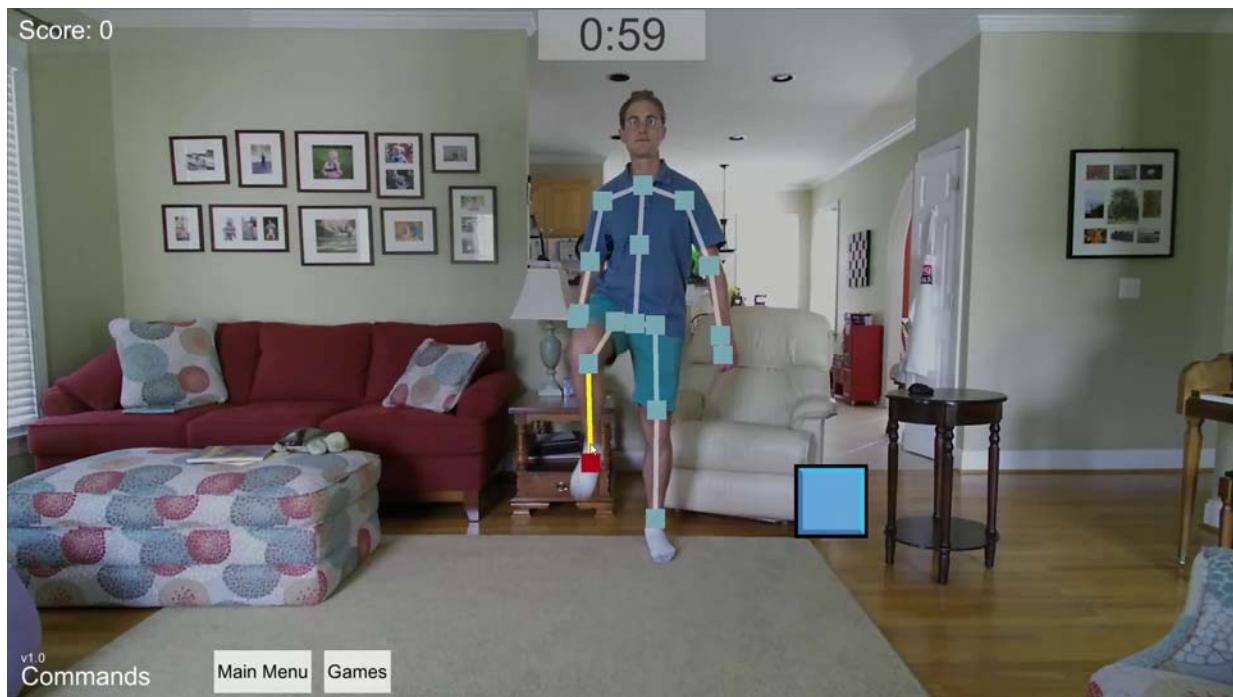


Figure 30: Critter Stomp game, leg raised for stomp

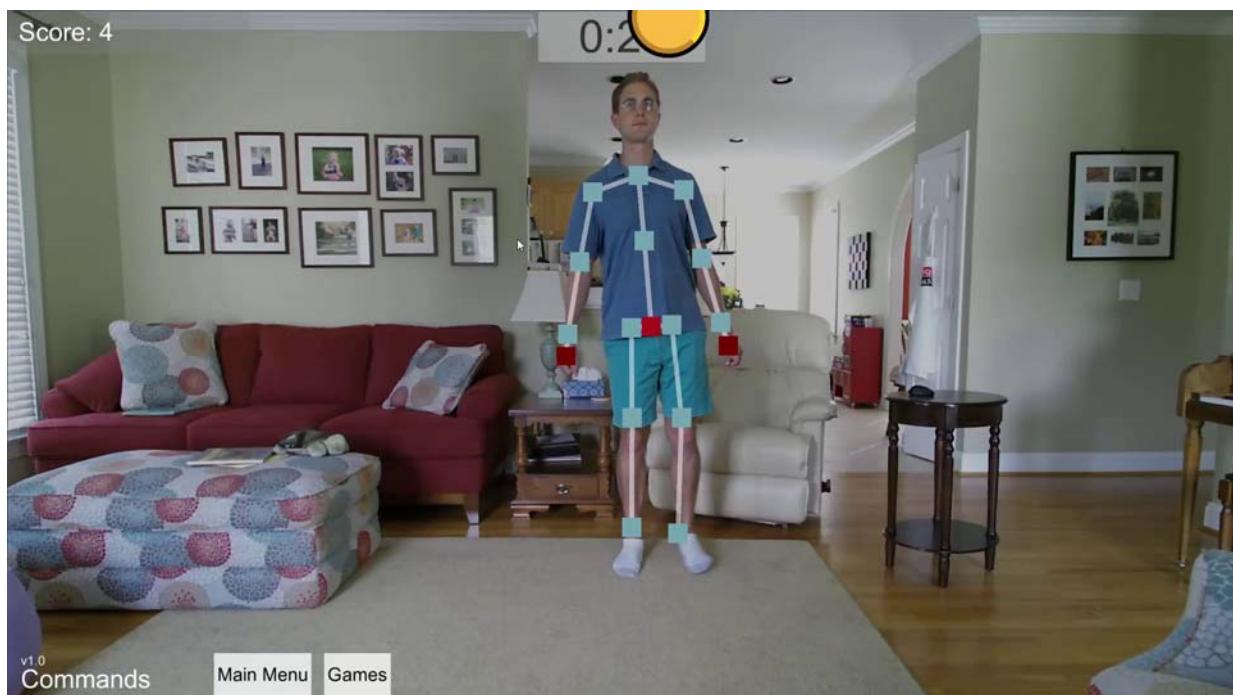


Figure 31: Critter Catch Game

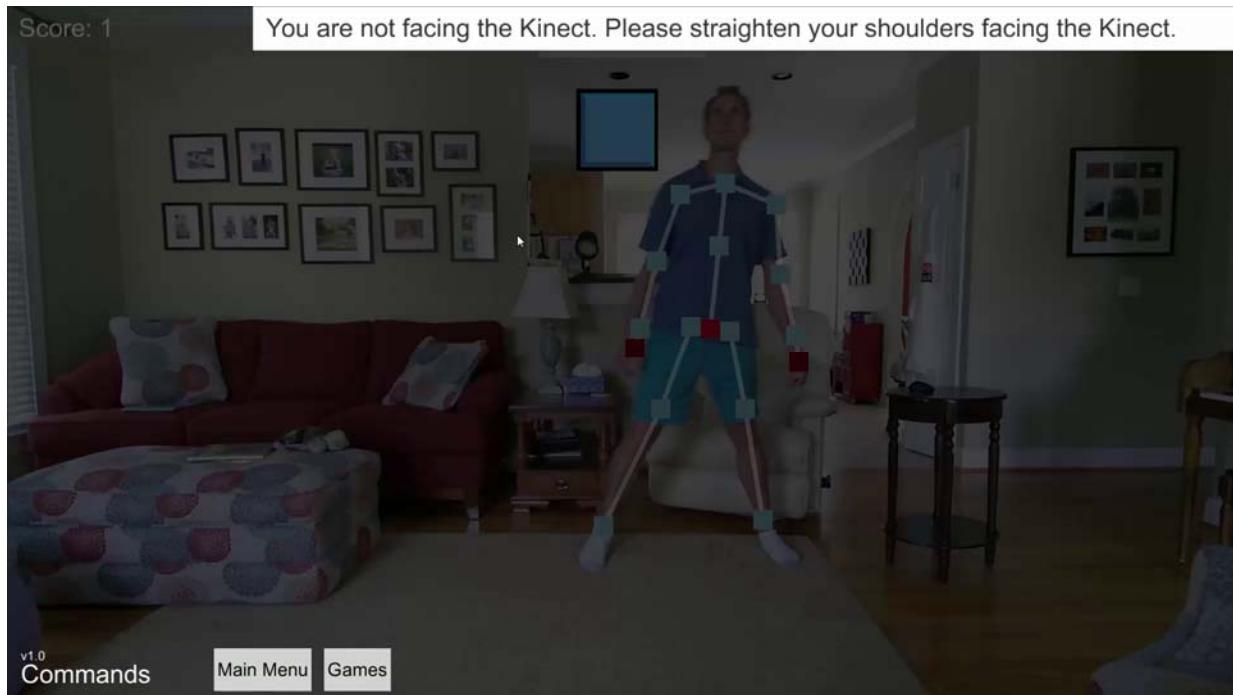


Figure 32: Critter Catch feedback

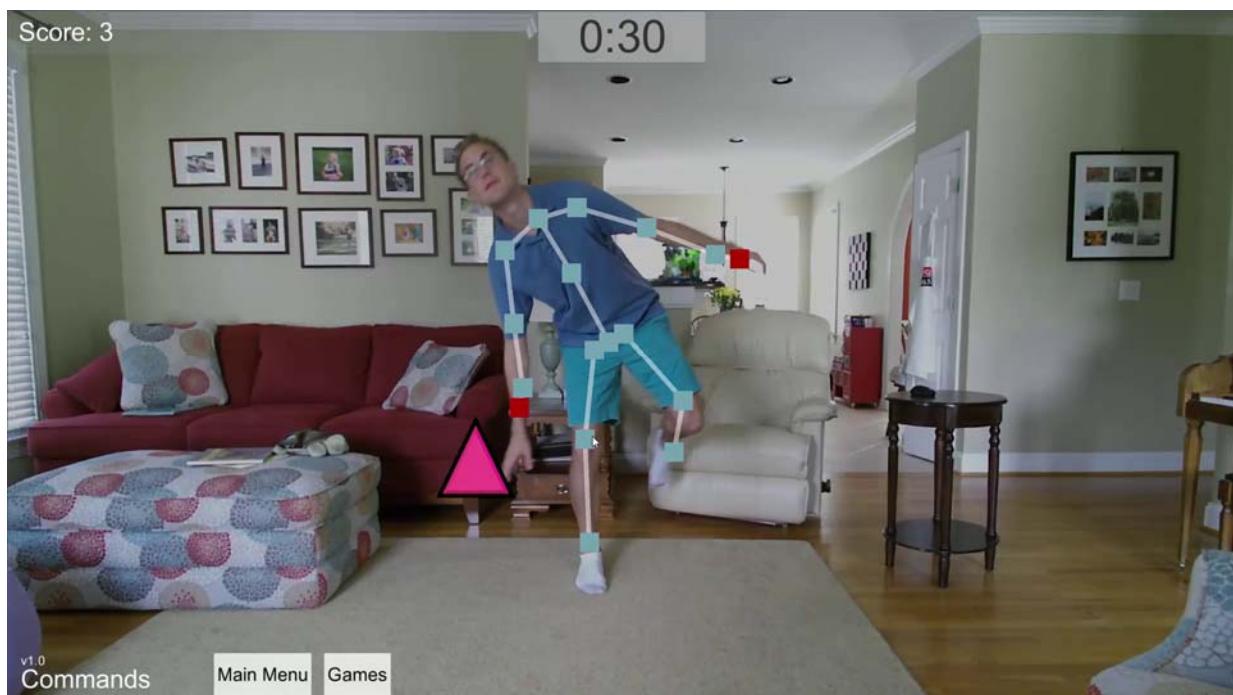


Figure 33: Critter Pong game

Task 6 (Evaluation)

The purpose if this task is to evaluate the MOVER system through a pilot study, to be performed if the Option is funded. During the current reporting, we have planned the pilot study of MOVER in the Spaulding facilities, determined our measures, and revised our IRB application to recruit and collect this data. We have requested a no-cost time extension to the effort to be able to execute this study. If this extension is approved, we will proceed with the study.

Significant Changes to Technical Approach to Date

There have been no significant changes to the technical approach to date.

Deliverables Submitted This Period

During the current reporting period, we submitted 4 quarterly project status updates to the JPC-1 council.

Milestones Reached/Achieved During This Period

The progress under the above tasks details the milestones achieved this period.

PROJECT PLANS

Specific Objectives for Next Period

- Complete the final report

ISSUES OR CONCERNS

We have no technical issues or concerns at this time. As of the time of writing, the option period is yet unfunded, and we are therefore seeking methods to run the initial clinical trials as described in the option period.

EXPENDITURES

Total Contract Amount	\$767,388.00
Costs Incurred this reporting period	\$500,227.61
Costs Incurred to Date	\$731,579.36
Estimated % to completion	95%

Appendix A: MOVER Poster Presentation

Mobile, Virtual Enhancements for Rehabilitation (MOVER)

Charles River Analytics, Inc.
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David Young

Anne O'Brien, PT
Joyce Liu, PT
Ross Zafonte, DO
Catherine Adams-Dister, PT

Abstract: MOVER is a system to reduce the cost and increase the effectiveness, availability, and accessibility of Warfighter physical rehabilitation. MOVER features: (1) virtual coaches to provide interactive guidance and mentoring; (2) integration with commercial 3D sensors to track patient movements; (3) integration with commercial video games to target cognitive impairments and increase motivation; (4) a mobile application to provide education and information; and (5) a therapist interface to accurately report patient progress.

Benefits: Lengthy inpatient treatments are extremely costly, especially for complex conditions such as traumatic brain injury (TBI), and they are not available to all patients. MOVER being developed to enhance outpatient rehabilitation, improving the quality, effectiveness, and cost efficiency of these interventions. Ultimately, this enables military health systems to provide more and better care for injured Warfighters.

Architecture

```

graph TD
    Patient --> MOVERMobile[MOVER Mobile Application]
    Therapist --> TherapistInterface[Therapist Interface]
    MOVERMobile <--> RemoteServer[Remote Server Secure Database]
    TherapistInterface <--> RemoteServer
    RemoteServer <--> COTSInput[COTS Input Devices]
    RemoteServer <--> VideoGame[Video Game Console]
    COTSInput --> ControlMapping[Control Mapping on Laptop]
    VideoGame --> ControlMapping
    ControlMapping --> RemoteServer
  
```

Therapy Targets

Current focus on traumatic brain injury (TBI)-induced motor and balance limitations

- Lengthy inpatient treatments are costly* to MTFs and VAMCs,
- ultimately reducing number and types of services offered
- Outpatient treatments are available, however
- Not widely used for all rehabilitation interventions
- Patients often lack adherence due to
 - confusion about exercises
 - perceptions of lack of time
 - forgetting
 - perceptions of helplessness
 - overall lack of motivation (Jette et al., 1998; Sluijs, Kok, & van der Zee, 1993)



Interaction

Current Development Build

Acknowledgment: This material is based upon work supported by the United States Army Medical Research and Materiel Command under Contract No. W81XWH-13-C-0021.

Appendix B: MOVER Quad Chart



Mobile, Virtual Enhancements for Rehabilitation (MOVER)

Charles River Analytics, Inc. | PI: Dr. James Niehaus

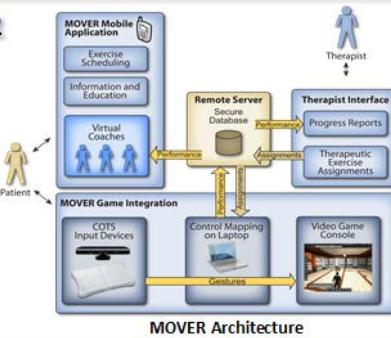
Summary

Problem: Today's warfighters are sustaining physical and cognitive wounds that require prolonged rehabilitation protocols. Inpatient delivery of treatment is expensive and manpower intensive; outpatient delivery relies on the patient to be sufficiently motivated and educated to "self-administer" the required rehabilitation protocols.

Solution: MOVER is a mobile, technology-enabled home-based rehabilitation intervention delivery system. The increased education, motivation, and support provided by MOVER will increase adherence to outpatient therapies, thereby reducing total rehabilitation costs and helping to ensure the success of out-patient rehabilitation interventions.

FY13	FY14	FY15
\$153,677	\$481,868	\$364,041

Core



MOVER Architecture

How it works

To provide education and information and to schedule therapeutic exercises:

- MOVER features mobile application for a smartphone or mobile device.

To provide interactive guidance and mentoring:

- MOVER features virtual coaches that appear on the mobile application.

To increase patient motivation, enable monitoring of patient progress, and reduce cost of deployment to the home environment:

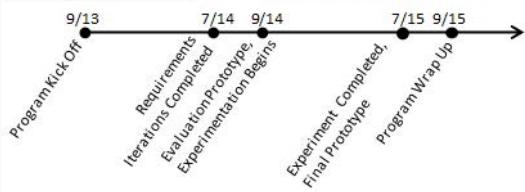
- MOVER provides a COTS technology-based multi-modal interactive environment for the patient to practice therapeutic exercises at home.

To enable therapists to accurately assess patient adherence and progress:

- MOVER provides printable summary reports of patient exercises through a web-based interface.

Programmatics

Period of Performance: 24 Months



Deliverables:

- Quarterly: Technical and financial progress reports
- Annually: Technical reports
- At contract completion: Technical report and final software prototype with therapist user manual and supporting hardware.